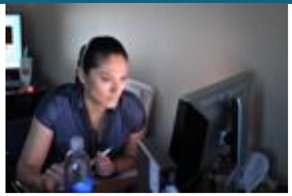
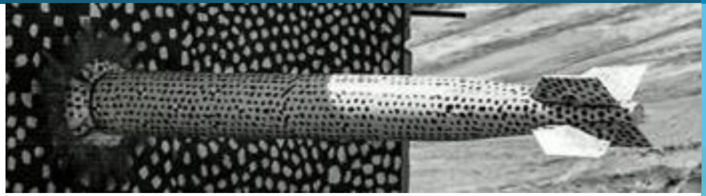
Sandia National Laboratories

Modeling the Thermal Performance of Falling Particle Receivers Subject to External Wind





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Presentation Outline

Background and Objectives

Modeling Approach

Parametric Wind Study

Conclusions

Falling Particle Receivers

Falling particle technology is a promising candidate to couple with next generation CSP systems

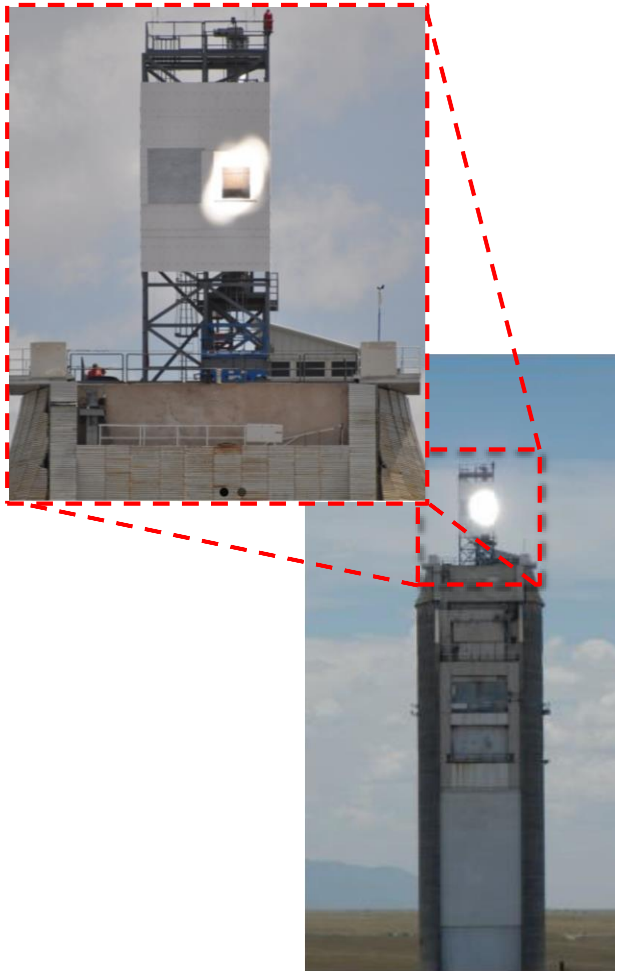
Falling particle receivers (FPRs) release a curtain of particles as the working fluid that are heated as they fall past the beam of concentrated solar radiation

Advantages:

- Can achieve high particle temperatures
- High thermal efficiency
- Low cost transfer medium
- Efficient storage

The Generation 3 Particle Pilot Plant (G3P3) is the next realization of falling particle technology currently being designed at the NSTTF

NSTTF FPR test loop in 2018



G3P3 Concept

NSTTF Falling Particle Experiments

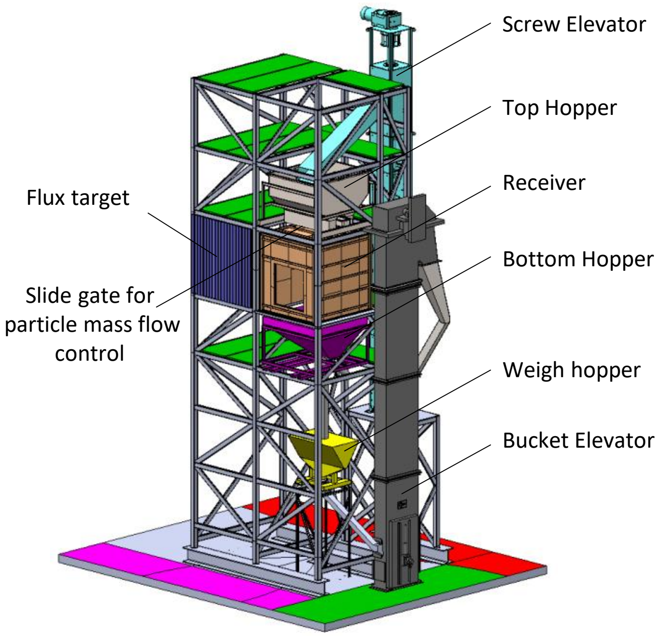
A series of 26 on-sun experiments were performed using the NSTTF FPR test loop in 2018 to evaluate FPR thermal performance and validate thermal models

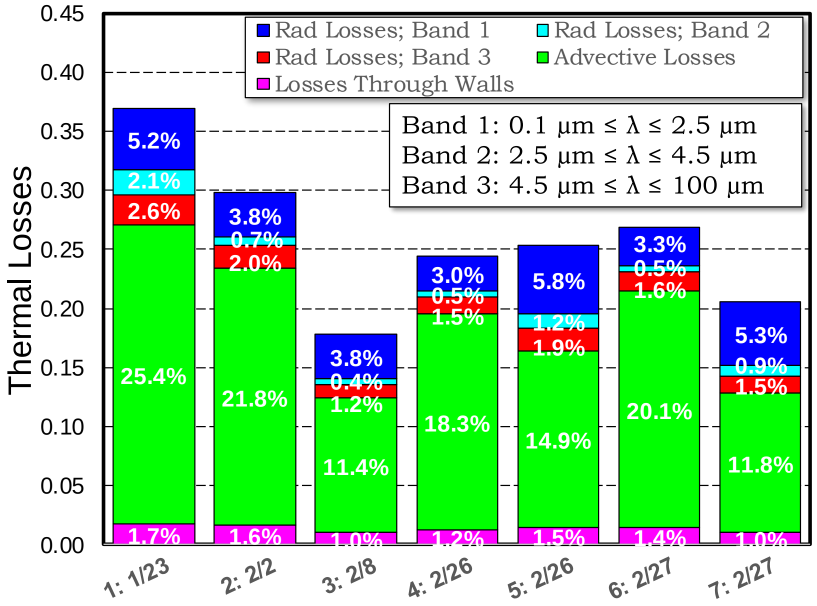
- A new particle mass flow rate measurement and control system had been implemented

When compared with experiments, early CFD models of the receiver demonstrated that **advective losses were large** and **the efficiency of the receiver was sensitive to wind**

To better understand the impact of wind for G3P3 design efforts, a parametric study of different wind conditions was performed

- Existing CFD models of the FPR at the NSTTF were modified to include the effects of wind





[Mills (2018)]

Modeling Objectives

The objectives of this study were threefold:

- Quantify the effect of wind direction and wind speed on the NSTTF FPR
- Evaluate the effect of different particle mass flow rates and particle diameters subject to wind
- Evaluate the FPR efficiency assuming wind and advective losses could be mitigated

The parametric study explored wind directions from N to S at winds speed of 5, 10 and 15 m/s

- Nominal receiver conditions: $q''_{irr} \approx \mathbf{1\ MW/m^2}$, $\dot{m}_{part} = \mathbf{10\ kg/s}$, $T_{i,part} = \mathbf{600°C}$

The thermal efficiency of the receiver is used to evaluate the thermal performance:

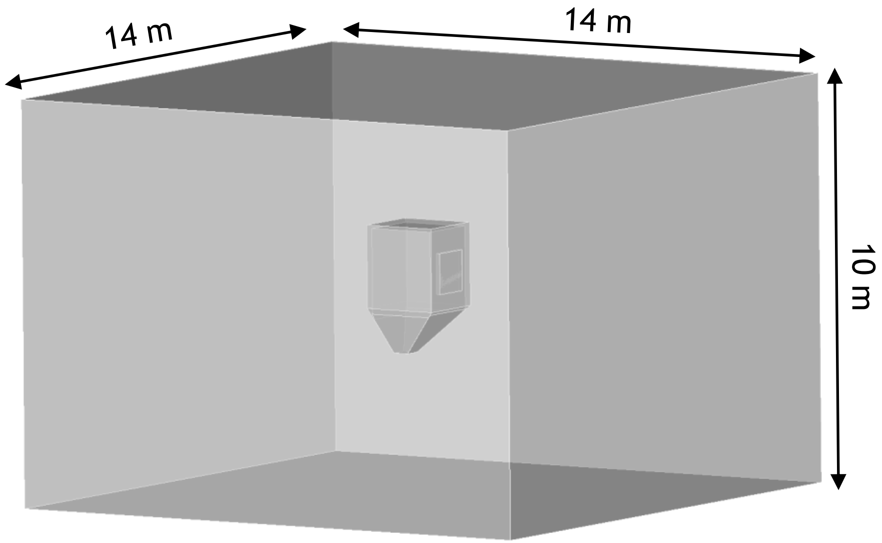
$$\eta_{th} = \frac{Q_{abs}}{Q_{in}} = \frac{\dot{m}\left(h_{out} - h_{in}\right)}{Q_{in}} = \frac{\dot{m}\int_{T_{in}}^{T_{out}} c_p\left(T\right)dT}{Q_{in}}$$

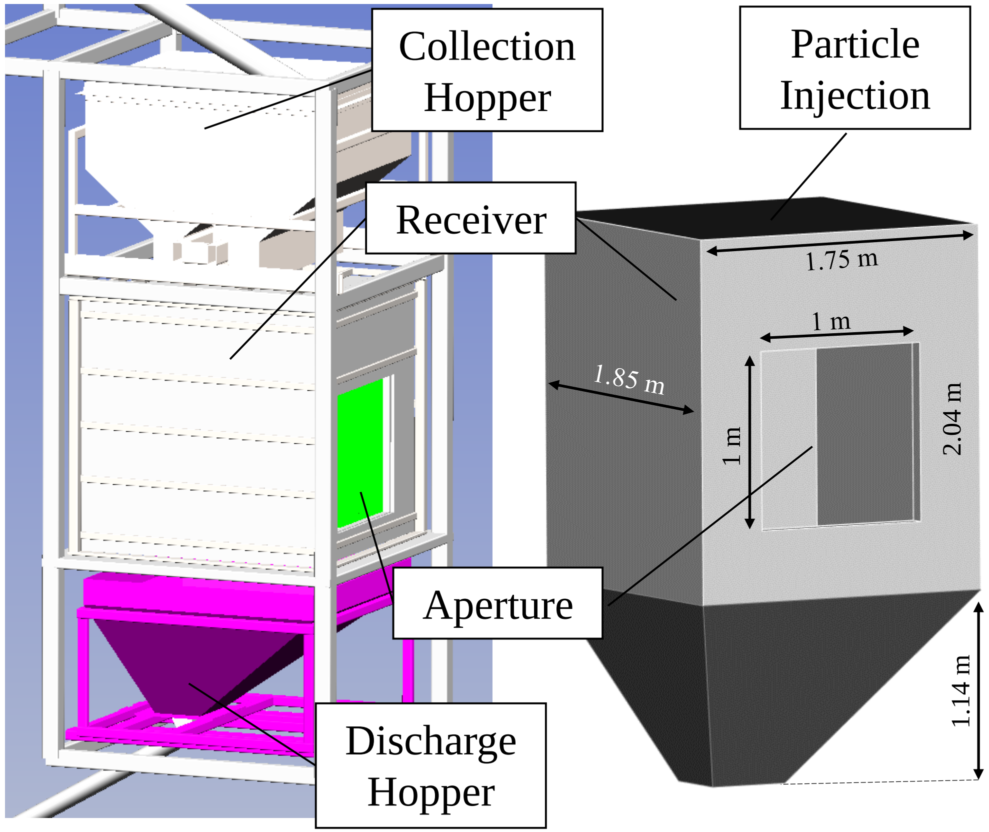
Falling Particle Receiver Model

A Lagrangian-Eulerian model was developed in ANSYS Fluent® of particles falling through air in the receiver

Falling particles were released from 600 injection sites and coupled to the air through drag forces, heat transfer, and turbulent interactions

Supporting structural elements were omitted from the domain for computational efficiency and generality





Falling Particle Receiver Model (contd.)

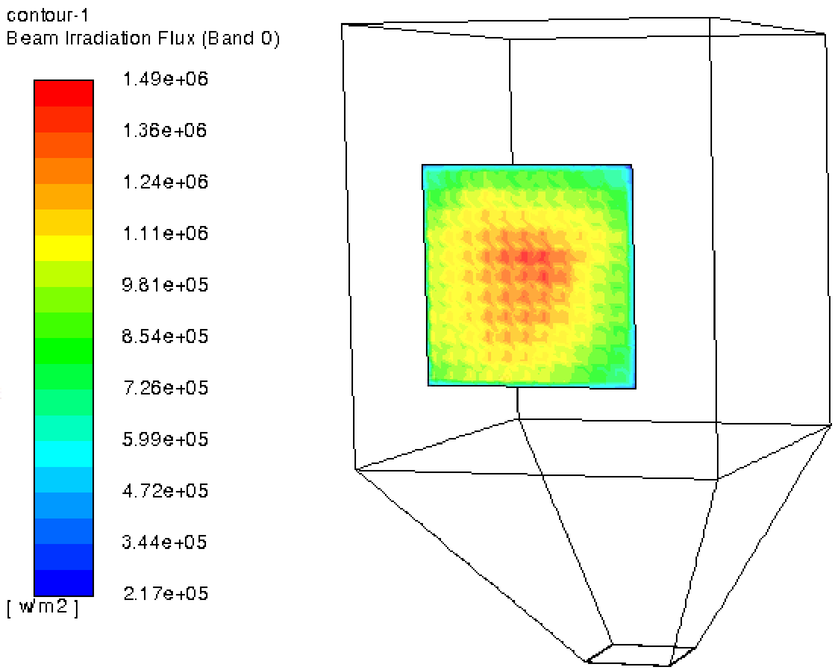
The two-equation, realizable k-ε turbulence model was applied in the model

- Fluent's 'scalable' wall functions were applied to provide a degree of mesh insensitivity

Particles were modeled as CARBO HSP 20/40 (82% Al_2O_3, 5% SiO_2, 3.5% TiO_2) with ~7% iron oxide

A non-grey, discrete-ordinates model was applied to model radiative heat transfer

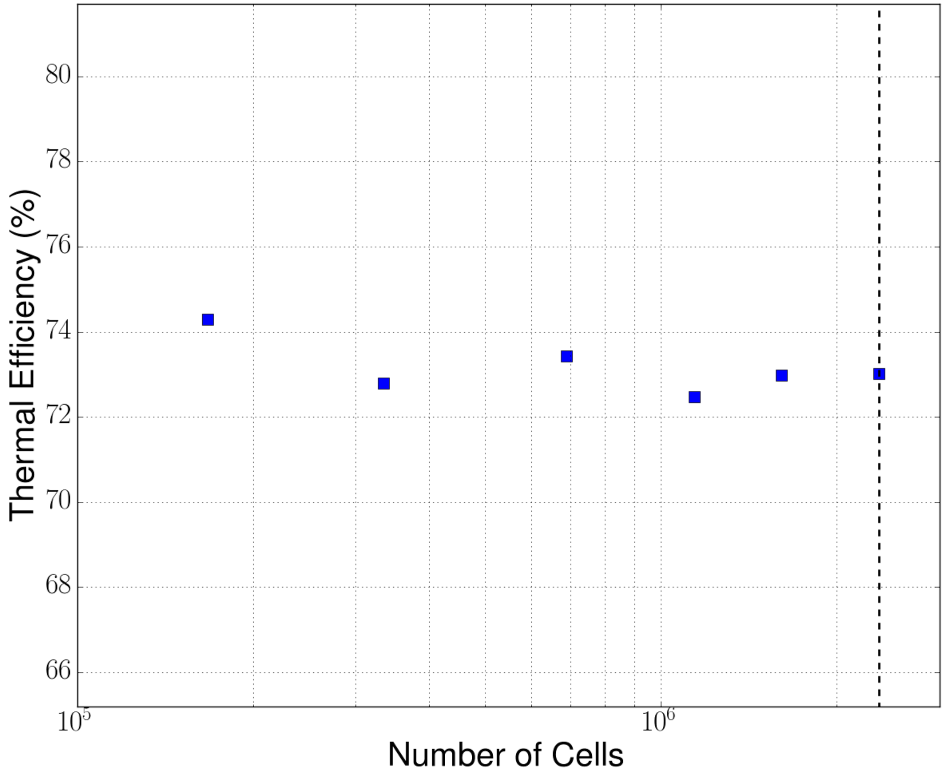
- Three wavelength bands (0.1 - 2.5 μm, 2.5 - 4.5 μm, 4.5 – 100 μm) were used in the DO model (1 band for solar radiation and 2 bands for thermal radiation)
- The incident beam was representative of an experiment from the NSTTF 2018 data providing ~1 MW/m^2 on the aperture

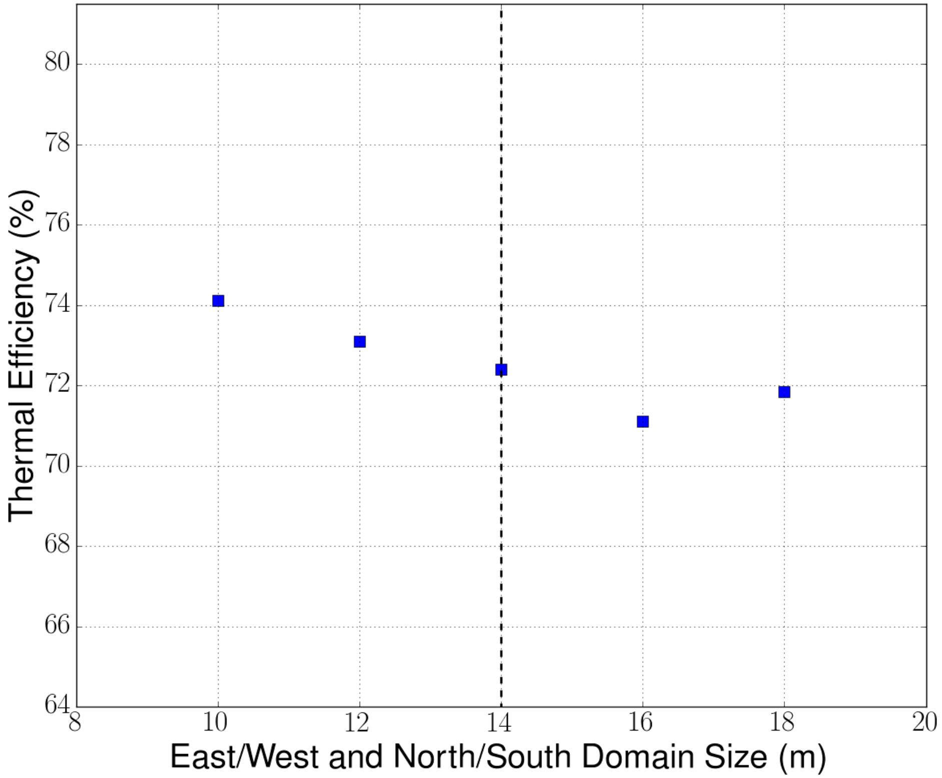


Solution Verification

To provide confidence that the spatial discretization and domain size was sufficient, solution verification tests were performed

- Using a mesh scaling approach, the chosen mesh resolution (2.364×10^6) was found to be sufficient
- The nominal domain size (14x14x10 m) was also found to be sufficient using consistent mesh sizing





Parametric Wind Study

For the nominal conditions:

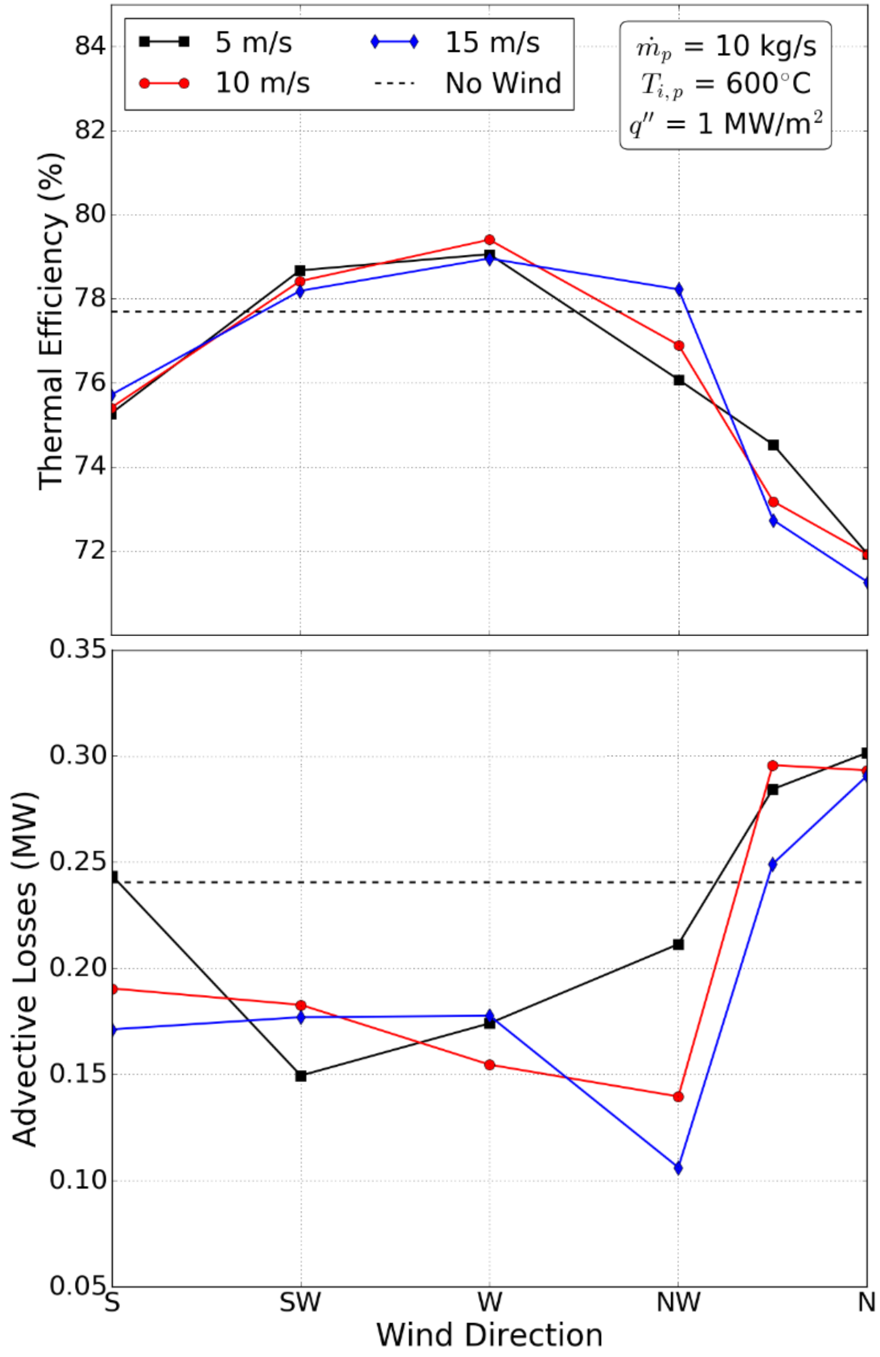
- $q''_{irr} \approx \mathbf{1\ MW/m^2}$, $\dot{m}_{part} = \mathbf{10\ kg/s}$, $T_{i,part} = \mathbf{600°C}$

Wind direction is more significant than wind speed

- Northern winds are the most detrimental

The thermal efficiency is inversely proportional to the advective losses

- Particle curtains were moderately influenced by the wind
- Wind primarily affects advective losses by changing the flow within the receiver cavity

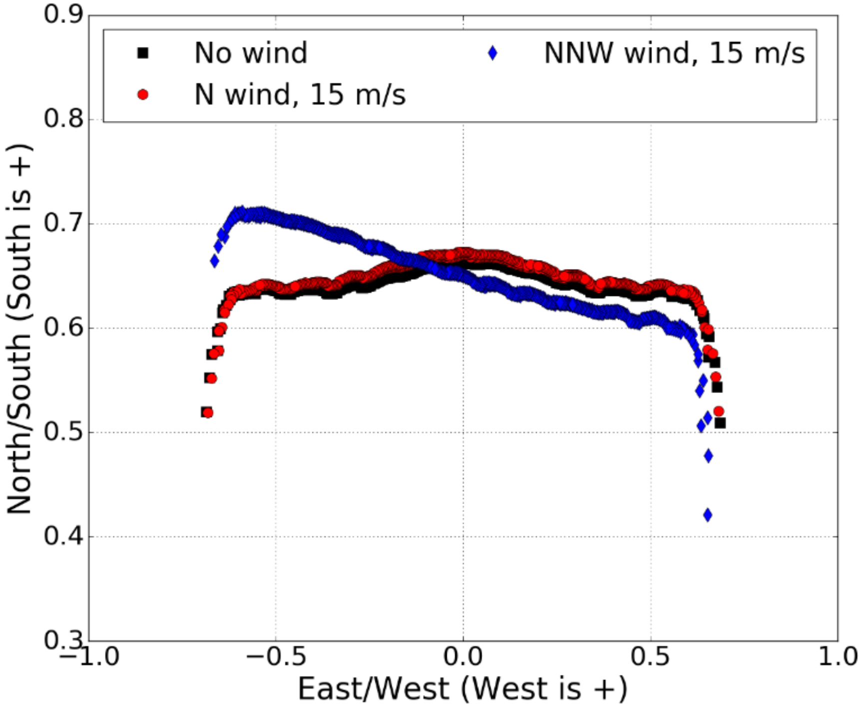


Parametric Study - Visualization

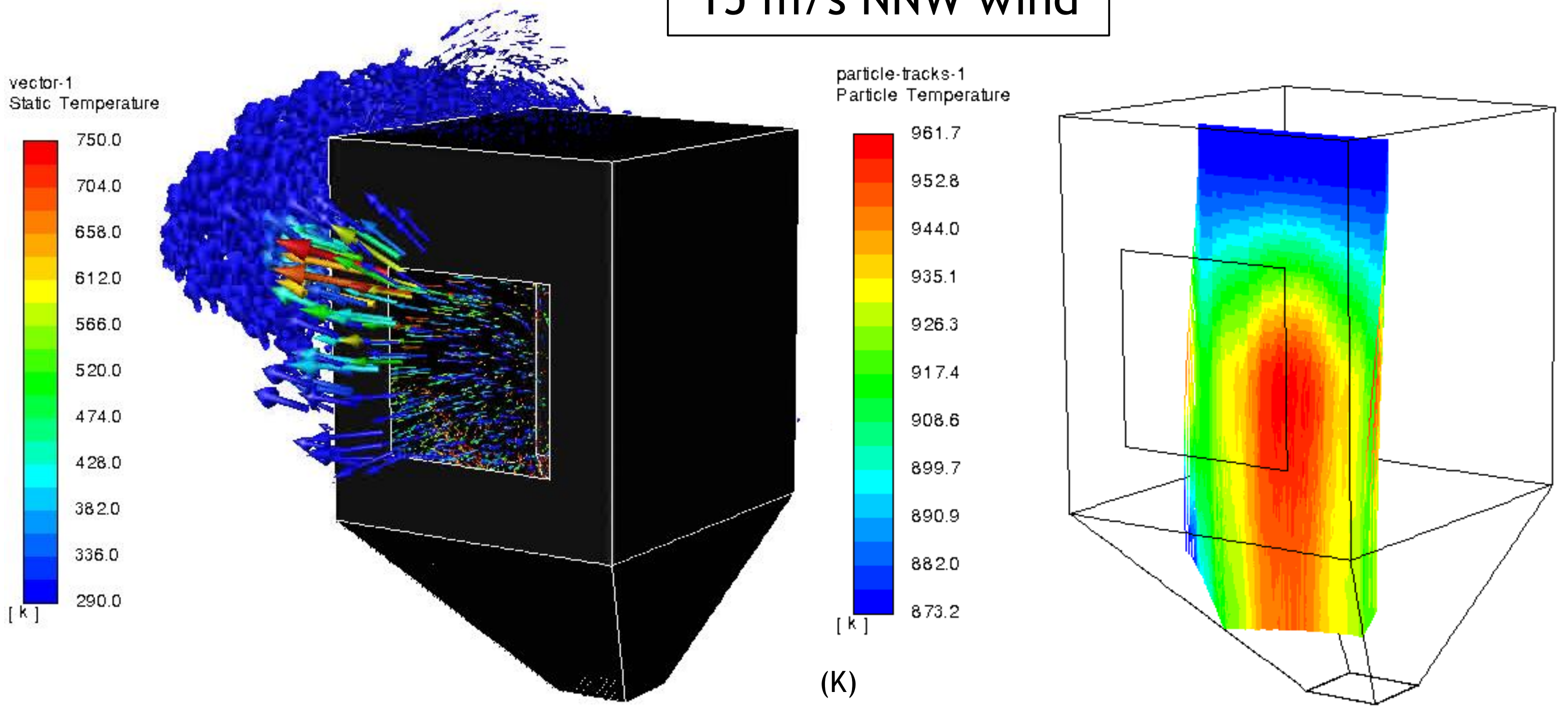
The falling particle curtain is affected by wind, but the positional change is only 5-7 cm

The flow in and out of the aperture is significantly affected by the wind

Curtain position below the aperture



15 m/s NNW wind

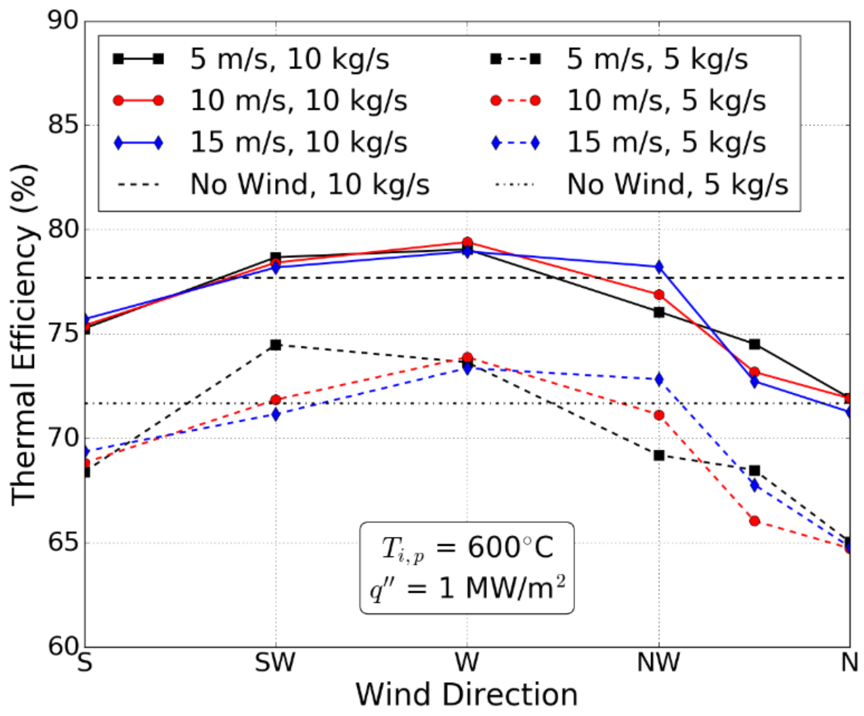


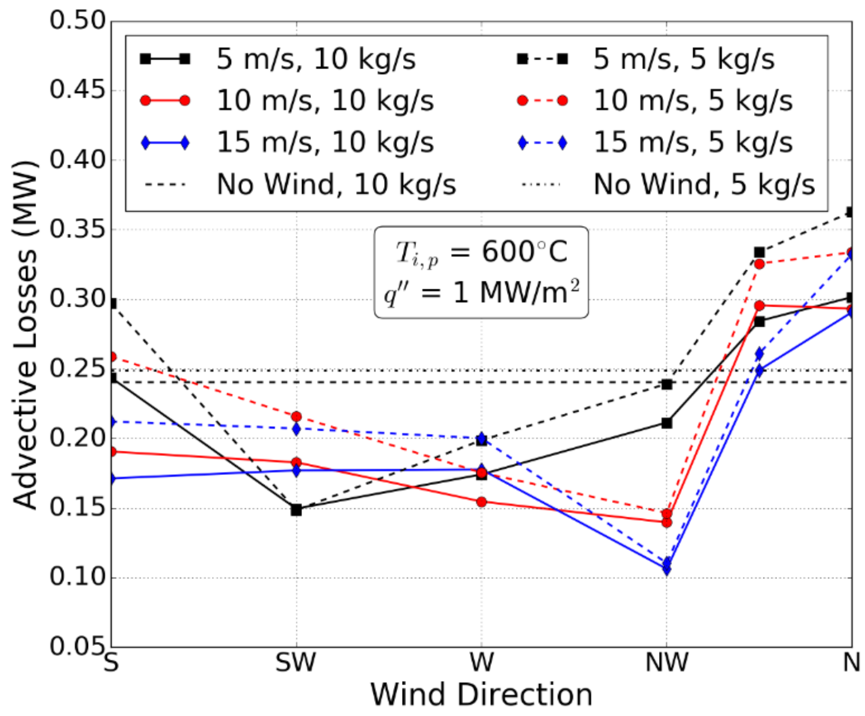
Effect of the Particle Mass Flow Rate

When decreasing the mass flow rate from 10 kg/s to 5 kg/s, a very similar trend was observed at lower efficiencies

Since similar advective losses were observed, most of the detriment was from additional **radiative losses** with a more transparent curtain

- At this scale, advective losses and wind effects are weakly correlated with particle mass flow rate



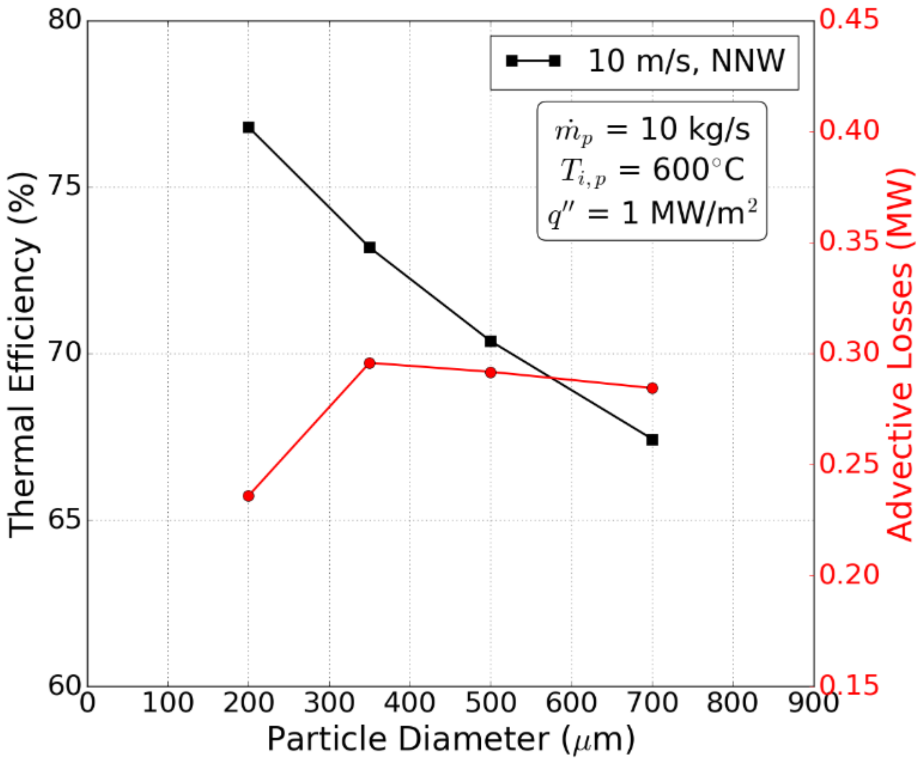


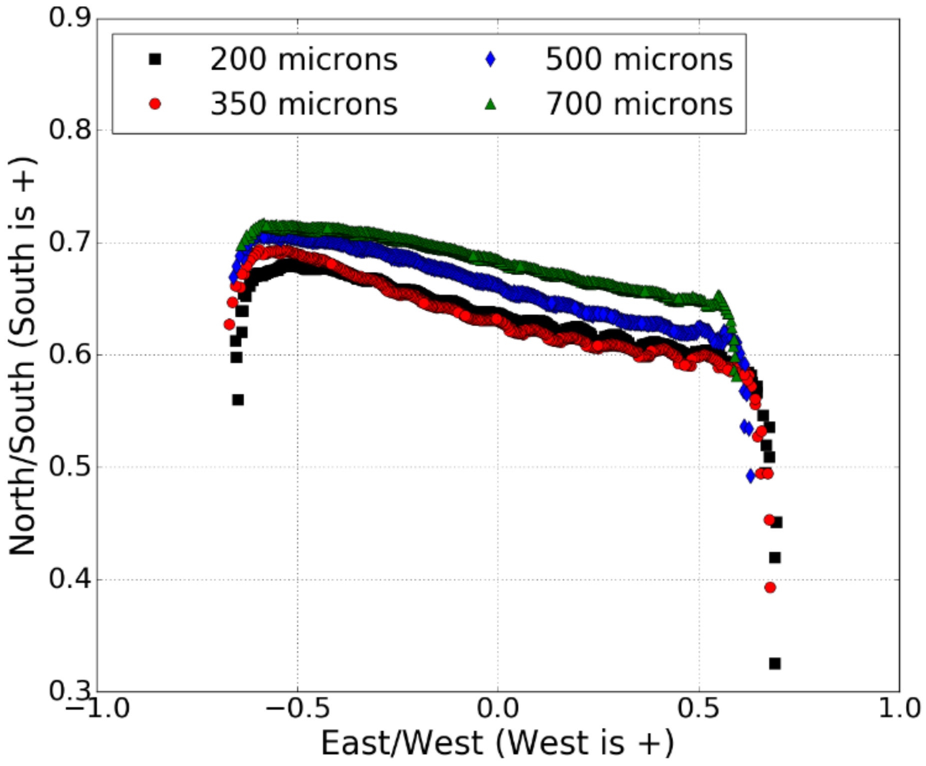
Effect of the Particle Diameter

The particle diameter was varied from 200 – 700 µm for a **NNW wind at 10 m/s**

For particle diameters ≥ 350 µm, advective losses were not significantly affected

- Curtain opacity was deemed to be more significant to the thermal efficiency subject to strong winds

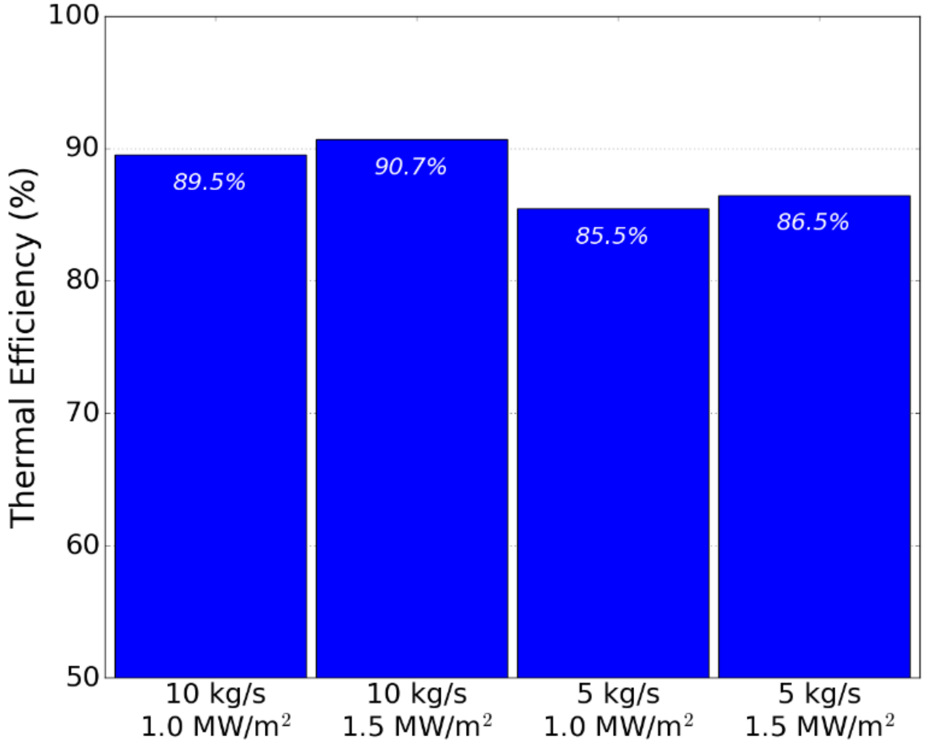


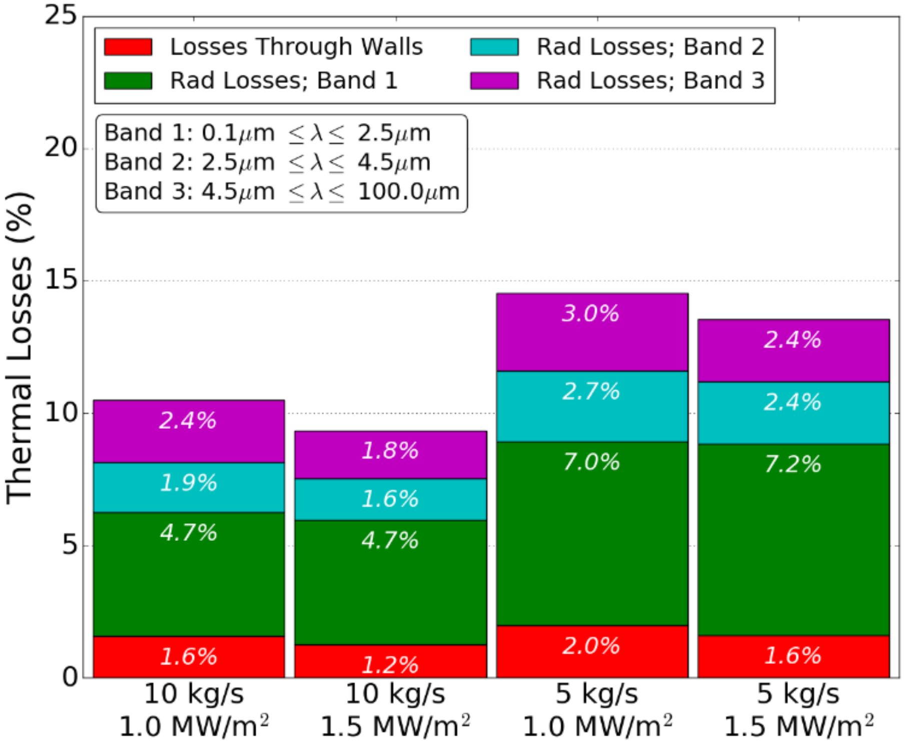


Mitigating Advective Losses

Under the assumption that advective losses could be mitigated, receiver efficiencies of 90% are attainable

- Possible strategies: quartz windows, air curtains (aerowindows), etc.
- Four simulations were performed assuming flow was obstructed at the aperture face

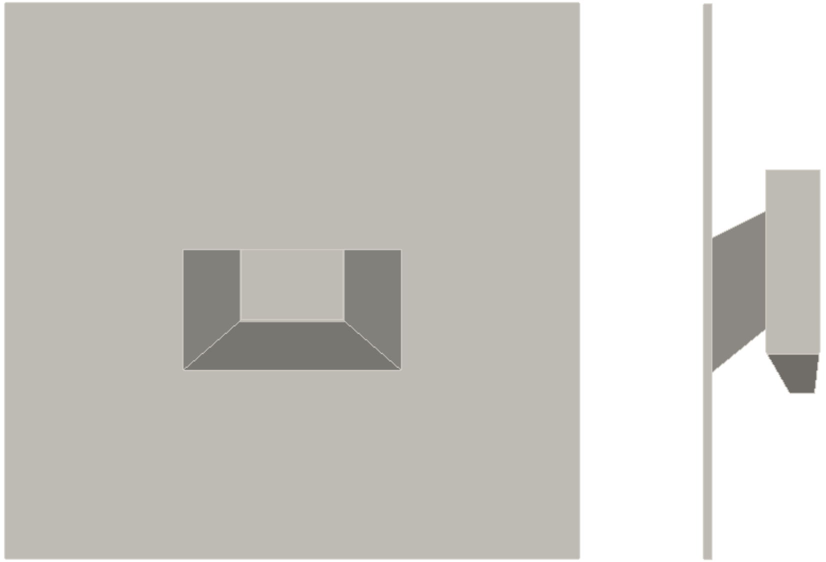


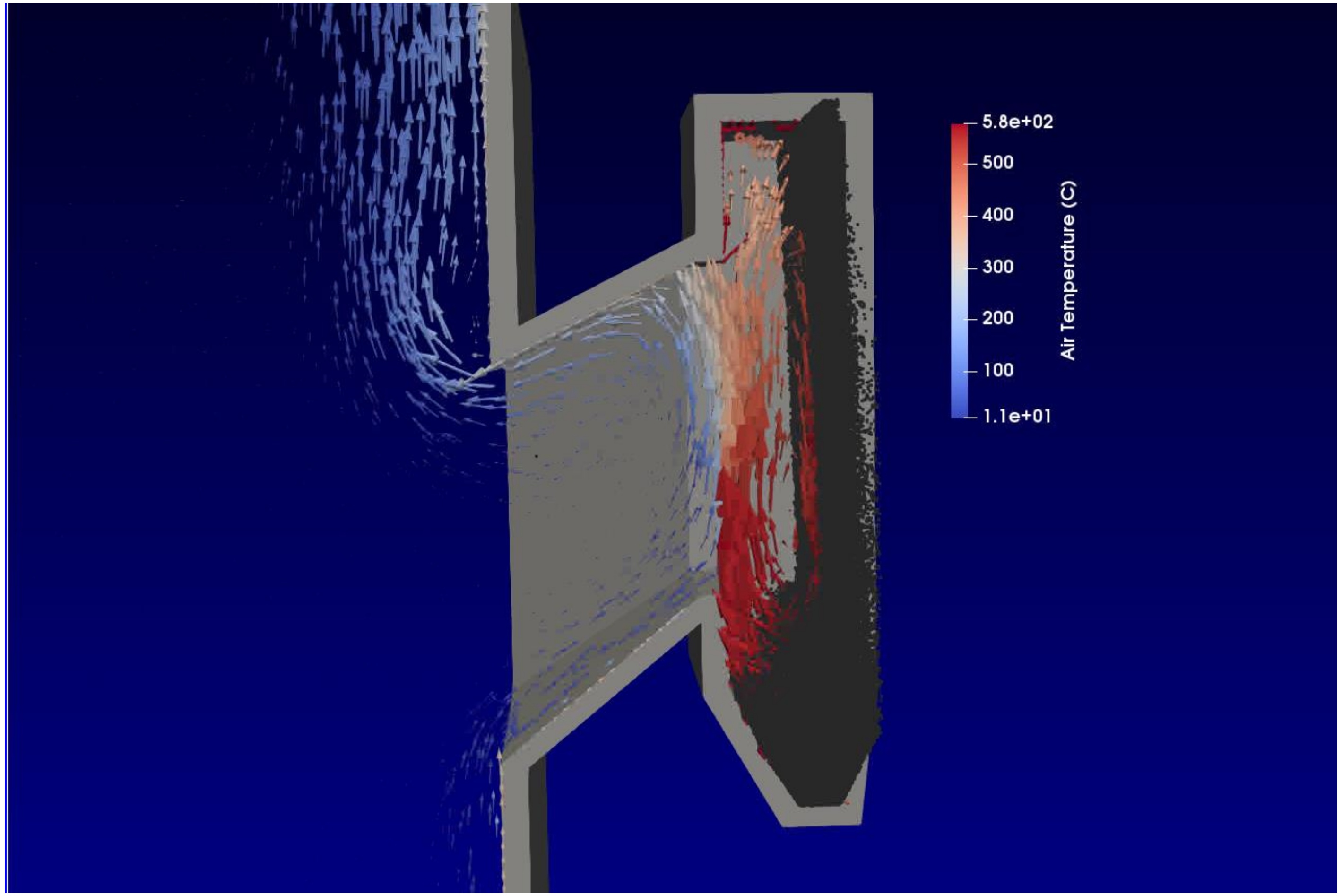


Optimizing the Receiver Geometry

Another strategy to reduce advective losses is to utilize the naturally entrained air from the falling particle curtain to inhibit flow out of the receiver

An extensive optimization study was performed to identify promising geometries





Conclusions

The thermal efficiency of the FPR was more sensitive to the wind direction as opposed to the wind speed up to 15 m/s

The particle mass flow rate and particle diameters ≥ 350 μm did not significantly change advective losses in a FPR and the interaction with wind

Receiver efficiencies up to 90% are achievable at this scale if advective losses and wind can be mitigated